



# CLIMATE CHANGE AND AGRICULTURE NEXUS IN SUB-SAHARAN AFRICA: THE AGONIZING REALITY FOR SMALLHOLDER FARMERS

George Kanyama Phiiri<sup>1</sup>, Anthony Egeru<sup>2,3</sup>, Adipala Ekwamu<sup>2</sup>

<sup>1</sup>Lilongwe University of Agriculture and Natural Resources (LUANAR), Malawi; <sup>2</sup>Regional Universities Forum for Capacity Building in Agriculture (RUFORUM), P.O. Box 16811, Kampala, Uganda; <sup>3</sup>Department of Environmental Management, Makerere University P.O. Box 7062 Kampala, Uganda.

## ABSTRACT

Climate change is one of the potent challenges facing smallholder farmers in sub-Saharan Africa in the recent past owing to the pattern and magnitude with which it presents the extreme events such as floods and drought. This review finds a general consensus that climate change is already happening in the region and the projections in the early, mid and end century all point to a much warmer future with highly variable rainfall across the region. These patterns in climate parameters is expected to trigger a negative trend in agricultural production for most food and cash crops in SSA. However, a few locations particularly the high-land locations over eastern Africa will be expected to become more suitable for the production of some cereals such as maize leading to increased production. Overall, at present and in the future unless strategic interventions are judiciously implemented smallholder farmers in SSA produce below the optimal levels with considerable yield gaps in nearly all the cereals, legumes and tubers grown. Efforts to unlock the potential of smallholder farmers under the current and projected climate change situation ought to focus on strategic and systemic implementation of; options that yield multiple benefits such as climate smart agriculture, investing in capacity building at both technical and farmer level, creating multiple opportunities for investment capital including availing smallholders with credit as well as mobilizing private financing. Further, investing at the development of functional early and early warning systems, investing in agricultural value chains through a strategic focus on agribusinesses and gaining and strengthening political commitment through a focus on policy and governance in agricultural frameworks and processes. Finally, a no-one fit for all paradigm ought to be upheld at all time while dealing with smallholder farmers in SSA owing to the dynamic and complex farming systems under which they operate.

**Key Words:** Adaptation, Capacity, Institutions, Resilience, RUFORUM, Yield gap

## INTRODUCTION

Sub-Saharan Africa is vulnerable to climate change for a couple of facts inherent in the region; high natural resource and agricultural dependence; poverty (58.9% living under multi-dimensional poverty (Alkire and Housseini, 2014); inadequate and ailing infrastructure; structural challenges at policy level (Ondige et al., 2013) and limited access and use of relevant and reliable agricultural inputs (Ringler et al., 2010). Understandably the interaction of the multiple stresses create a higher susceptibility of the region to climate variability and change as well as constraining the region's adaptive capacity (Connolly-Boutin and Smit, 2015). The impact of climate change on agriculture; food and livelihoods in SSA can no longer be under estimated. This because there is a general agreement in the scientific community that tem-

peratures have increased, and will further increase in the near term, mid and end century (O'Loughlin et al., 2014; Egeru et al., 2014). The SSA temperatures are expected to increase above the global average (Ringer et al., 2010) with varied performance in rainfall and seasons across the region (Shiferaw et al., 2014). For example, it is expected that rainfall will decrease in northern and southern Africa, increase over Ethiopian and East Africa highlands with increased frequency extreme events over the low lands (IPCC, 2007; Conway, 2009; Ringler et al., 2010). Temperature is particularly projected will increase leading to a level above tolerance range for most of the current crop varieties, cultivars and livestock species (Afenyo, 2015).

The debilitating impacts climate variability and change confers are wide ranging from perceived trigger of conflict

### Corresponding Author:

Anthony Egeru, Department of Environmental Management, Makerere University P.O. Box 7062 Kampala, Uganda.  
E-mail: a.egeru@ruforum.org

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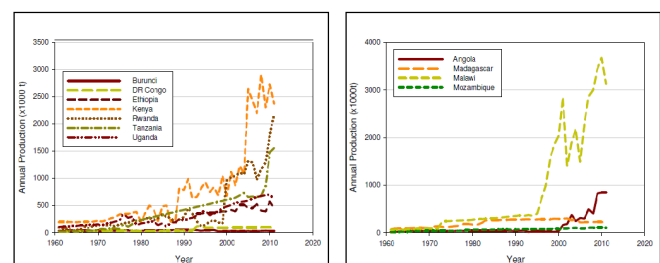
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(O'Loughlin et al., 2014) to production constraint among smallholder farmers in the region; these have become critical to decipher. Alterations in rainfall intensity (Songok et al., 2011), prevalence of extreme weather events including floods and droughts (Niang et al., 2014; Barasa et al., 2014; Egeru, 2014), spatial and temporal alterations in disease vectors and transmissions including trans-boundary livestock diseases (Chen et al., 2006), increased prevalence of heat events as well as escalation of desertification across the African continent (Reich et al., 2001) are all anticipated. With a couple of these impacts occurring from time to time, smallholder farmers in Africa are already facing a series of robust negative impacts of climate variability and change on agriculture including among others; losses in crop and livestock productivity; leading to loss of major livelihood defenses and a cyclic poverty (AGRA, 2014). Further, climate projections for most of sub-Saharan Africa reveal potential negative impacts including among others; disruptions in the length of the growing season, constrictions in the livestock-crop suitable locations, potential decline in crop and other agricultural yields with some countries expected to experience up to 50% declines (Boko et al., 2007; Ringler et al., 2010), and changes in agro-biodiversity (Niang et al., 2014). Climate change is also expected to worsen the nutrition challenge in Africa with an additional 132 million people becoming undernourished by 2050 (AGRA, 2014). Further, it's been shown that an increase by 1.2 to 1.9 will make more of the continent's population undernourished by 25% to 95% (central Africa +25%, East Africa +50%, Southern Africa +85% and West Africa +95%) (Munang and Andrews, 2014).

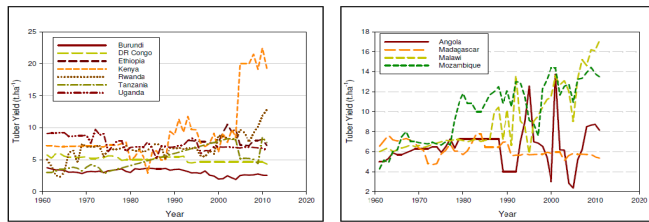
Production risks and costs associated with climate change are similarly unceasing. A focused analysis of these risks and costs is pivotal in prioritizing effective investments that will assist adaptation to the espoused changes. Schlenker and Lobell (2010) have showed that changes in SSA's mean aggregate production for maize, sorghum, millet, groundnut, and cassava were likely to be -22, -17, -18, and -8% respectively. Such precise information is vital for decision making on allocation of scarce resources for adaptation relative to many other developmental needs. However, precise information on climate change is particularly deficient in sub-Saharan Africa, more so, that which is relevant and applicable to smallholder farmers. Thus, farmer decisions often than not are based on past experiences yet the changes particularly occurring are laced with extreme weather that challenge the conventional practices of smallholder farmers. By all indications, climate change is seen as a real potent threat on Africa. All hope is not lost, because even amidst climate change Africa still has potential to feed itself but this requires getting the right mix of the agricultural value chain 'cocktail' in Africa right (Munang and Andrews, 2014).

## Smallholder farmers and agricultural production in sub-Saharan Africa

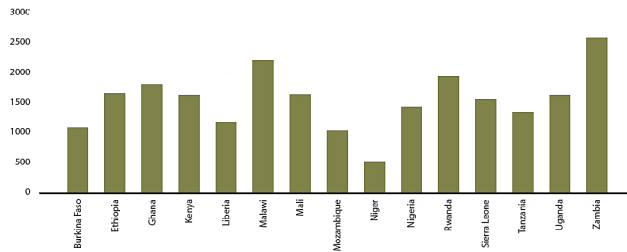
Smallholder farmers are a vital artery of food security in sub-Saharan Africa. Over 80% of the farms in SSA are under smallholder ownership (about 50 million farms) and management and about 70% of whom are female farmers (AGRA, 2014; Schaffnit-Chatterjee, 2014). These farms however consist of small parcels and patches of land with constrained input resources. Subsequently, Africa's smallholder farmers are often described as 'resource poor' (Mignouna et al., 2008). Whereas sub-Saharan Africa is generally 'perceived' to have fertile soils, the farming practices escalate the degradation of these soils through nutrient mining activities (Drechsel et al., 2001). Further, production gaps abound; the vertical yield is constrained. Compared to other regions in world; sub-Saharan Africa's yield per hectare far lags behind in nearly every crop. For example, potatoes production is generally below 10 t/ha for most countries in eastern and central Africa. Even those that are above, their tuber yield riddles with inter-annual variability with an unceasing variability into 2020 (Figure 1 and 2). Further, the scenario from the cereal production is not any better; yields have generally remained stagnated at less than 25% of the potentially attainable yields with many parts of the region merely attaining <1.5 t/ha (a few countries have managed to attain >1.5 t/ha but marginal; Figure 3) compared to the potential that is greater than 5 t/ha (AGRA, 2013; Mutege and Zingore, 2014). The exception in the trap of stagnated growth in production is southern Africa that experienced a more than 350% increase in yields over a 50 year period (Ward et al., 2014). Thus, it is apparent that SSA is the only region that has failed to improve agricultural productivity for a couple of reasons that are either directly or indirectly orchestrated including among others; under-investment, poor infrastructure, insecure land tenure, unfavourable price policies and weak institutions (Schaffnit-Chatterjee, 2014).



**Figure 1:** Annual Potato Production in Selected Countries of Eastern and Central Africa (left) and Southern Africa (right) (Source: Quiroz et al., 2014).



**Figure 2:** Average Potato Tuber Yield in Selected Countries of Eastern and Central Africa (left) and Southern Africa (Quiroz et al., 2014)

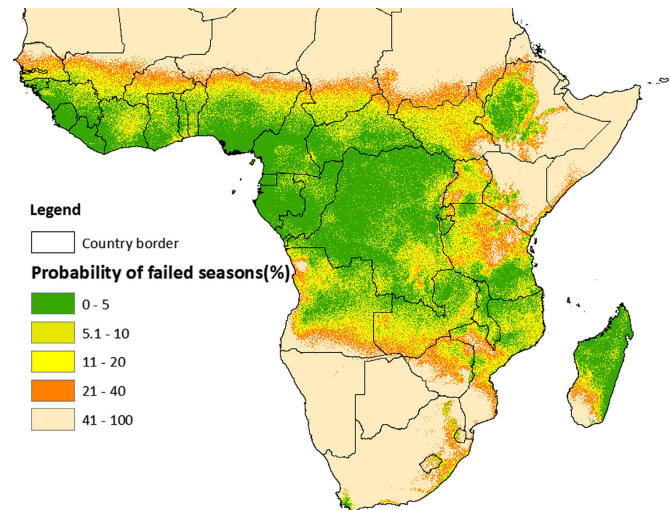


**Figure 3:** Cereal yield production in selected countries in SSA in 2010 (Source: AGRA, 2013)

### Smallholder agriculture in the face of climate change in sub-Saharan Africa

Many parts of sub-Saharan Africa are predisposed to climate variabilities and extreme events such as drought with devastating impacts. Regional analysis of extreme climate events particularly drought show an increased presence over the last 20 years with a shortened return period of eastern Africa (Williams and Funk, 2011; Shiferaw et al., 2014). Climate change is certainly making the prevalence of these extreme events over Africa more pronounced (Schmidhuber and Tubiello, 2007; Kahare, 2014). The impacts on crops will be devastating particularly that most of the crops in Africa are already grown close to their limits of thermal tolerance (Conway, 2009). It is also anticipated that a 10-40% risk of failed seasons during major cropping calendar is experience in SSA, climate change will likely make this situation worse (Figure 4; Shiferaw et al., 2014). It is also expected that by 2025 the per capita water availability will be worsening with an increased water scarcity, stress and vulnerability. By the end of the century, grain crops (that constitute the major staples) will be most affected with up to 72% decline in wheat yields and up to 45% yield reductions in maize, rice and soybean (Figure 5; Adhikar et al., 2015). Smallholder farmers in SSA are also heavily reliant on autonomous adaptation (a reaction of farmers in response to a climate change event (Calzadilla et al., 2013). A high certainty pertains that climate change, particularly increased temperatures, will negatively affect crop yields in sub-Saharan Africa (Ward et al., 2014). And, had temperatures to stay to the pre-1960 period, only

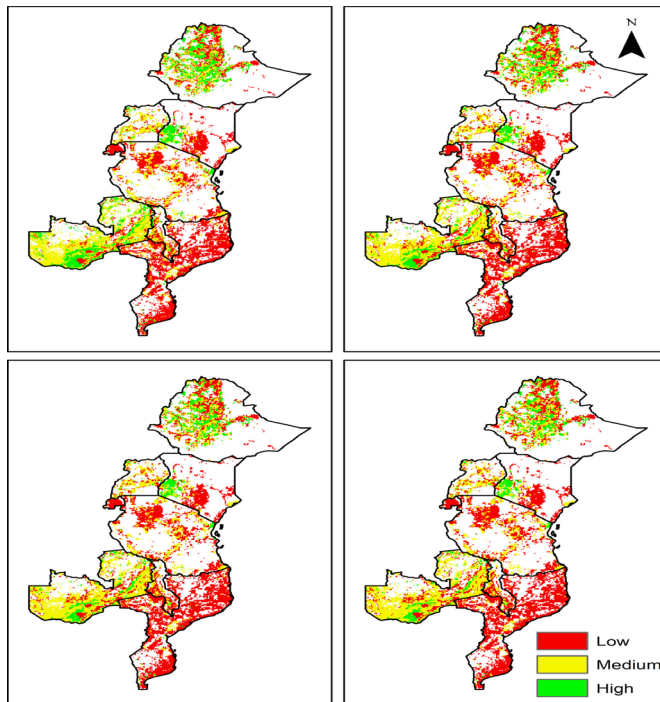
then would a 32% yield gap increase have been possibly observed between SSA and other developing countries (Barrios et al., 2008). In Uganda, coffee production is being affected with further projections showing that the coffee production zones will significantly shrink (Nandozi et al., 2012). Overall, the damage of climate change will remain negative for most crops in SSA (Schlenker and Lobell, 2010).



**Figure 4:** Probability of years in which growing season is likely to fail due to drought in sub-Saharan Africa (Source: Shiferaw et al., 2014)

However, all hope is not lost, some regions in SSA are projected will experience improved agricultural production. Calzadilla et al. (2013) show that in some areas of SSA agricultural production will increase by 25 per cent. This will be associated with expected increase in rainfall in some parts of eastern Africa including the Horn of Africa and central Africa (Collier et al., 2008). Further, within the region there are some islands of potential gains in production. For example maize yield is expected to increase in Kenya and Rwanda in 2030 and 2050 by 15% and 11% in 2030 and 18% and 15% by 2050 respectively. The gains in Rwanda and Kenya are expected to arise from the beneficial effects of temperature increases that bring growing season temperatures close to optimum in the temperate/tropical highlands (Adhikar et al., 2015). Some 17 GCMs from the Comprehensive Climate Change Scenarios also show that millet will experience a slight increase (<5%) in SSA by 2050 (Ringler et al., 2010). Smallholder farmers have opportunity to harness from the potential gains arising but in the overall, the focus ought to be exerted on facilitating their capacity to adapt to the probable certainty of uncertain future. Particularly, ensuring the smallholder farmers are in better position to adjust to the nonlinear responses that abound to arise in the internal dynamics of the climate system.





**Figure 5:** Current (a) and projected maize yield by the end of 21st century under B1 (b), A1B (c) and A2 (d) scenarios (Adapted from Adhikar et al., 2015)

The limitations with climate change and smallholder agriculture in SSA pertains to the manner of interactive and causative studies undertaken. For example, most climate change projections are conducted on a medium to long term basis (10, 20, 30, 60, 80 years). Yet many decisions other than climate that often influences smallholder agricultural production in the region do not focus at this time length. Thus, information is available at ‘an unavailable proportions’; particularly to the political elite that influence various activities in their respective countries. This indicates that there remains a considerable challenge to addressing the climate change downscaling and modeling that is relevant at small geographic level (Ifejika Speranza, 2010). Obviously this will require commendable financial, infrastructural and human resources investment; including building a critical mass of technical personnel. Further, the challenges regarding the understanding of climate change impact on smallholder farmers relates to three inter-related conditions; firstly, there is a lack of standardized definitions of the smallholder farming system, and therefore of standard data above the national level in difficult. Secondly, the intrinsic characteristics of the smallholder systems, particularly their complexity, their location-specificity, and their integration of agricultural and nonagricultural livelihood strategies is complex; and thirdly, they are vulnerable to a range of climate-related and other stressors (Morton, 2007).

## Unlocking the potential of smallholder farmers in SSA amidst climate variability and change

Focusing at helping smallholder farmers grow is not an option; because over 90% of all farms in SSA are cultivated and managed by smallholder farmers and account for 80% agricultural production and this pattern is expected to stay into the mid-term of this century. Secondly smallholder farmers and their farms have potential to be efficient in terms of total factor productivity (Molua et al., 2010; Calzadilla et al., 2013; Schaffnit-Chatterjee, 2014). Further, smallholder farmers in SSA are not devoid of ingenuity in tackling climate change within their midst. Several communities have had deliberate (aimed at reducing overall vulnerability to climate shocks-adaptive strategies) and unintended (often to manage their ex-post impacts-coping strategies) actions towards building resilience through stimulating the existing ecosystems and available natural resource bases (Morton, 2007; Munang and Andrews, 2014; Afenyo, 2005). However, the pattern of the extreme events is at the center of undermining their ability, resources, options and therefore capacity to adapt (Afenya, 2015).

The on-going discourse on climate variability and change adaptation and mitigation in agriculture points to four core challenges that relate to producing: (i) more food, (ii) more efficiently and sustainably, (iii) under more uncertain production conditions, and (iv) with reductions in GHG emissions (Villanueva and Rocío, 2011). In that case, unlocking the potential of smallholder farmers amidst climate change is complex, requiring; consideration of critical components including among others: soil health, water conservation, livelihood diversification, institutional capacity at various levels; national and local levels that is in position to champion the processes inherent in adaptation (Adhikar et al., 2015). It is also emerging that a greater attention to the understanding, articulating and where it is inevitable providing rebuttal to the paradigms such as the market-led model that is creating an altered marginalization of smallholder farmers in sub-Saharan Africa (Rajaonarison, 2014).

Several options have been rallied for smallholder farmers to adopt. One of such options with ‘hyped’ opportunities is climate smart agriculture (CSA) albeit not utterly new but a rebrand of sustainable land management (SLM). In its present form and discourse; CSA is perceived to offer the best bet option to addressing the four core challenges of climate change adaptation and mitigation in agriculture. This is because CSA represents a set of strategies that can help address the challenges of meeting the growing demand for food, fibre and fuel, despite the changing climate and fewer opportunities for agricultural expansion on additional land through increasing resilience to weather extremes, adapting to climate change and decreasing agriculture’s greenhouse

gas emissions that contribute to global warming (Steenwerth et al., 2014). However, for equity issues; the CSA in its broad sense is controversial among smallholder farmers. There are other complex facets that hinder uptake of the CSA as an innovation system but also as a host of strategies that it transmits; particularly because often than not it tends to challenge farmers' decisions through altering the risks and uncertainty and incorporating new information into their traditional knowledge-processing systems. Overall, because CSA assures the triple benefits and particularly that it provides for opportunities for context-specific driven agro-ecological approaches and solutions; it is promising options for unlocking smallholder farmers' potential in SSA.

Investing in agricultural value chains through a focus on agribusiness; shifting from focusing on SSA as a development challenge to a business opportunity and financing agriculture and agribusinesses in the region guarantees potential for unlocking smallholder farmers amidst climate change challenge (Schaffnit-Chatterjee, 2014). Financing agriculture facilitates smallholder farmers to take advantage on several fronts; farmers are able to access information tools and technologies that help build their resilience to climate change (IFAD, 2012). It also offers smallholder farmers with opportunities to enhance resource use efficiency that also increases production in the face of climate change as well as protecting the environment (Ifejika Speranza, 2010). Whereas agricultural financing is a conduit to unlock the potential of smallholder farmers, the real focus of this financing and investment ought to increase the proportion of climate finance going into adaptation, and to secure a flow of resources to locations and populations where adaptation needs are greatest. Further, there is need to strengthen mobilizing private financing through creative innovative finance and insurance products that improve both risk and management and access to capital for adaptation actions, among the smallholder farmers (Ayemaw, 2014). It is only when agricultural financing is able to reach the smallholder farmers; in non-constraining yet constructive pathways that agricultural investment and financing will provide the unlocking potentials and will the smallholders be in position to take advantage of these opportunities to strengthen their adaptive capacity and build resilience.

Whereas there has been a general perception that SSA has fertile soils; smallholder farmers struggle with low soil fertility. For example, approximately 40% of the soils in SSA have low nutrient capital reserves (<10% weatherable minerals), 25% suffer from aluminum toxicity while 18% have a high leaching potential (Sanchez et al., 2003). Improving soil health through approaches such as integrated soil fertility management (ISFM) technologies offers opportunities for smallholder farmers to adapt to and mitigate climate change while simultaneously unearthing their potential in terms of

increased productivity, resilient agro-ecological systems and strengthened livelihoods. ISFM provides a mechanism to enhance crop productivity whilst maximizing the agronomic efficiency of the applied inputs; it thus contributes to sustainable intensification which is a necessary ingredient to addressing rural poverty and natural resource degradation in SSA (Vanlauwe et al., 2015). There are initiatives within the region to address the soil fertility challenge; these initiatives focus on a broad spectrum of concerns including; (i) improving soil fertility by maximizing biological nitrogen fixation (N2Africa); ii) create content for extension; iii) increasing smallholder farmers' access to locally appropriate fertilizers; iv) creating conditions for smallholder farmers to be able to afford fertilizer use by creating market access, credit and finance access, and v) assistance to farmer organizations and advocacy for national policies that are favourable to smallholder farmers (Dhamankar et al., 2014). It is also important to note that effective solutions that will be of help to smallholder farmers under the current state of climate change should be able to support resilient systems and must cut across agricultural, environmental and socioeconomic objectives (Tully et al., 2015).

Supporting smallholder farmers in hotspot locations in SSA requires considerable investment in agricultural research, to develop new varieties of crops, identify alternative crops that are acceptable to the farmers and their families, and/or develop new farming techniques for the area that will help farmers to continue to grow their current crops (Thomas and Rosegrant, 2015). However, investment in agricultural research in SSA is not possible without significant investment in capacity building of next generation of scientists in Africa. Evidence from a survey conducted on behalf of the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) revealed severely constrained research capacity in the National Agricultural Research Institutes (NARIs) due to limited number of PhD level staff to design and engage in quality research (Kibwika, 2013). Nonetheless, there are efforts in the region to bolster the research capacity through training; the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) in the last 11 years has coordinated and supported the training of 1373 MScs and 315 PhDs in SSA. Capacity development under RUFORUM has not only focused at developing technical capacity but also that of smallholder farmers through innovative programmes such as the Community Action Research Programme (CARP) (Egeru et al., 2015). These are illustrative milestones within the region in building technical capacity that need further support for escalation. Important in this context, is the strengthening of the knowledge management systems; not just investment in research but assurance of the timely, intelligible and communicable knowledge to and among farmers is very profound in ensuring that farmers are able to make timely, informed decisions as well as press

for accountability from the various power brokers and policy leaders. It is generally noted that capacity development provides opportunity to expand the coping range and strengthen the capacity of a system to adapt to climate change, including variability (Masters and Duff, 2011).

The potency of climate change among smallholder farmers arises from its ability to disarm the traditional calendars including the predictions made by the communities. Thus, investing in early warning and early warning systems is pivotal to facilitating adaptation to climate change and exploiting its potential benefits. Early warning is the provision of timely and effective information, through identified institutions, that allows individuals exposed to a hazard to take action to avoid and/or reduce their risk and prepare for effective response. On the other hand, early warning systems include a chain of concerns among others: the understanding and mapping the hazard; monitoring and forecasting impending events; processing and disseminating understandable warnings to political authorities and the population, and undertaking appropriate and timely actions in response to the warnings (Humanitarian and Development Network, 2010). As alluded previously, over 70% of crop production in SSA comes from vulnerable rainfed smallholder farmers; most of whom operate in fragile environments; ecologically, geographically and economically (ISDR, 2008). Smallholder farmers in this category would benefit from predictions, particularly those focused on extreme events such as drought. Further, predictions need not to happen for the sake; but these need to focus at the environment of concern; in this case providing smallholders with customized forecast information that can reliably inform them about the onset, cessation and intra-seasonal variations in order to reach decisions such as what, when and how to plant/harvest will be a step in the right direction (Masinde and Bagula, 2011).

Political commitment through policy and governance in agricultural policy frameworks and processes that support climate change adaptation is central to smallholders in the current and future state. Political support is a fundamental resource in adaptation efforts (Kabat et al., 2012). Adaptation policies that underscore that climate change is just one stress in a complex environment cocktail offer a much better opportunity to smallholder farmers and decision makers to undertake systems thinking and solution search (Ziervogel et al., 2006). Further, because adaptation is highly local, its effectiveness depends on local and extra-local institutions through which incentives for individual and collective action are structured. Institutional arrangements that define the governance processes also structure risks and sensitivity to climate hazards, facilitate and/or impede individual and collective responses, and shape the outcomes of such responses (Agrawal, 2010). A thorough understanding of how these function in relation to climate and associated impacts is cen-

tral to developing interventions that can influence the adaptive capacity and adaptation practices of smallholder farmers. In addressing smallholder farmer's adaptation needs; politically sensitive questions of responsibility and equity often arise at various levels (Burton et al., 2006); wading these issues to the sidelines will be committing strategic suicide as well as relegating smallholders to further vulnerability position.

## CONCLUSION

This review set out to explore the linkage between smallholder farmers and climate change in SSA as well as to exposition what potential options exist for unlocking the potential of smallholder farmers under a climate change situation. Smallholders are and will in the foreseeable future continue in the agricultural production and therefore in the food security equation in SSA. However, smallholder farmer's production is still below the optimal capacity and climate change constitutes a major threat that will further weaken their production potential. There is overly a general agreement that the climate of SSA Africa will change with temperatures expected to rise, rainfall seasonality (inter and intra) expected to change and extreme events including drought and floods becoming prevalent. It therefore remains that smallholder farmers in SSA require urgent action to tackle climate change various levels. Investments that have potential to unlock smallholder farmers capacity under climate change situation include: investing in approaches and options with multiple benefits such as climate smart agriculture, investing in information and information systems including early warning and early warning systems, capacity building of smallholders and other actors involved in agriculture, availing financial resources for investment, strengthening institutions at various levels, and investing in technologies and invest in technical and structural capacities. Finally, we are cautious of the fact that 'no-one fit for all' approach can be adopted in the endeavor to unlock the potential of smallholder farmers in SSA because of the dynamic and complex farming systems under which the smallholders operate.

## REFERENCES

1. Adhikari, U., Nejadhashemi, A. P., & Woznicki, S. A. (2015). Climate change and eastern Africa: a review of impact on major crops. *Food and Energy Security*, 4(2), 110-132.
2. Afenyo, S. J. (2015). A review of food security implications of climate change in sub-Saharan Africa. *Africa Intelligence's Africa Enviro*. Available from: [http://www.consultancyafrica.com/index.php?option=com\\_content&view=article&id=993:a-review-of-food-security-implications-of-climate-change-in-sub-saharan-africa-&catid=92:enviro-africa&Itemid=380](http://www.consultancyafrica.com/index.php?option=com_content&view=article&id=993:a-review-of-food-security-implications-of-climate-change-in-sub-saharan-africa-&catid=92:enviro-africa&Itemid=380)
3. Agrawal, A. (2010). Local institutions and adaptation to climate change. *Social dimensions of climate change: Equity and vul-*



- nerability in a warming world, 173-198.
4. Alkire, S., Housseini, B., & Series, O. S. (2014). Multidimensional Poverty in Sub-Saharan Africa: Levels and Trends. OPHI Working Paper. Vol. 81, 3.
5. Alliance for a Green Revolution in Africa AGRA (2013). The Africa Agriculture Status Report 2013: Focus on Staple Crops. Nairobi, Kenya. Available from: <http://agra-alliance.org/our-results/agra-status-reports/>
6. Alliance for a Green Revolution in Africa AGRA (2014). Africa Agriculture Status Report 2014: Climate Change and Smallholder Agriculture in Sub-Saharan Africa. Nairobi, Kenya. Issue No. 2. Available from: <https://ccafs.cgiar.org/publications/africa-agriculture-status-report-2014-climate-change-and-smallholder-agriculture-sub>
7. Barasa, B., Kakembo, V., Mugaga, F., & Egeru, A. (2013). Comparison of extreme weather events and streamflow from drought indices and a hydrological model in River Malaba, Eastern Uganda. *International Journal of Environmental Studies*, 70(6), 940-951.
8. Boko M et al 2007 Africa Climate Change 2007: Impacts, Adaptation and Vulnerability (Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change) ed ML Parry, O F Canziani, J P Palutikof, P J van der Linden and C E Hanson (Cambridge: Cambridge University Press) pp 433–67.
9. Burton, I., Diring, E., & Smith, J. (2006). Adaptation to Climate Change: International Policy Options. PEW Center on Global Climate Change. Available from: [http://www.c2es.org/docUploads/PEW\\_Adaptation.pdf](http://www.c2es.org/docUploads/PEW_Adaptation.pdf)
10. Calzadilla, A., Zhu, T., Rehdanz, K., Tol, R. S., & Ringler, C. (2013). Economywide impacts of climate change on agriculture in Sub-Saharan Africa. *Ecological Economics*, 93, 150-165.
11. Chen, H., Githeko, A.K., Zhou, G., Githure, J.I., Yan, G. (2006). New records of *Anopheles arabiensis* breeding on the Mount Kenya highlands indicate indigenous malaria transmission. *Malar J* 5:17. doi:10.1186/1475-2875-5-17
12. Collier, P., Conway, G., & Venables, T. (2008). Climate change and Africa. *Oxford Review of Economic Policy*, 24(2), 337-353.
13. Connolly-Boutin, L., & Smit, B. (2015). Climate change, food security, and livelihoods in sub-Saharan Africa. *Regional Environmental Change*, 1-15.
14. Conway, G. (2009). The science of climate change in Africa: Impacts and adaptation', Imperial College London, Grantham Institute for climate change, Discussion Paper No. 1, 24. London, October 2009.
15. Dhamankar, M., Mapfumo, P., Kleijn, W. (2014). Strategic partnership for the Fertile Grounds Initiative. A rapid appraisal of networks, organizations, programmes, projects and private sector engagement in Soil Fertility Initiatives in Sub Saharan Africa. KIT. Available from: [http://knowledge4food.net/wp-content/uploads/2015/01/150107\\_KIT-report-soil-fertility-study.pdf](http://knowledge4food.net/wp-content/uploads/2015/01/150107_KIT-report-soil-fertility-study.pdf)
16. Drechsel, P., Kunze, D., & De Vries, F. P. (2001). Soil nutrient depletion and population growth in sub-Saharan Africa: a Malthusian nexus?. *Population and Environment*, 22(4), 411-423.
17. Egeru, A. (2014). Assessment of forage dynamics under variable climate in Karamoja sub-region of Uganda. Doctoral dissertation, University of Nairobi. Available from: [http://erepository.uonbi.ac.ke/bitstream/handle/11295/75781/Egeru\\_Assessment%20of%20forage%20dynamics%20under%20variable%20climate%20in%20Karamoja%20sub-region.pdf?sequence=1](http://erepository.uonbi.ac.ke/bitstream/handle/11295/75781/Egeru_Assessment%20of%20forage%20dynamics%20under%20variable%20climate%20in%20Karamoja%20sub-region.pdf?sequence=1)
18. Egeru, A., Nampala, P., Massa-Makuma, H., Osiru, M., & Adipala, E. (2015). Innovating for skills enhancement in agricultural sciences in Africa: the centrality of field attachment programmes. Regional Universities Forum for Capacity Building in Agriculture (RUFORUM).
19. Egeru, A., Osaliya, R., MacOpiyo, L., Mburu, J., Wasonga, O., Barasa, B., Aleper D., & Majaliwa Mwanjalolo, G. J. (2014). Assessing the spatio-temporal climate variability in semi-arid Karamoja sub-region in north-eastern Uganda. *International Journal of Environmental Studies*, 71(4), 490-50
20. Humanitarian and Development Network (2010). Emerging Challenges for Early Warning Systems in context of Climate Change and Urbanization. A Joint Report Prepared by DKKV/ Platform for Promotion of Early Warning/ UNISDR with Inputs from Partner Organizations and Coordinated by Humanitarian & Development Network. Switzerland. Available from: [http://www.unisdr.org/files/15689\\_ewsincontextofccandurbanization.pdf](http://www.unisdr.org/files/15689_ewsincontextofccandurbanization.pdf)
21. IFAD, (2012). Adaptation for Smallholder Agriculture Programme ("ASAP"). IFAD. Available from: <https://www.gov.uk/government/publications/adaptation-for-smallholder-agriculture-programme-asap>
22. Ifejika Speranza, C. (2010). Resilient Adaptation to Climate Change in African Agriculture, 311 p., Bonn 2010. ISBN 978-3-88985-489-6.
23. Inter-Governmental Panel on Climate Change, IPCC (2007). 'Fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC): Africa 2007', 2007, <http://www.ipcc.ch>
24. ISDR (2008). 3rd African drought adaptation forum report, Addis Ababa, Ethiopia, 17–19 September 2008. ITU, 2008. Ubiquitous sensor networks (USNs). ITU-T's Technology Watch Briefing Report series, No. 4 (February). Available from: [www.itu.int/dms\\_pub/itu-t/oth/23/T230100000\\_40001PDFE.pdf](http://www.itu.int/dms_pub/itu-t/oth/23/T230100000_40001PDFE.pdf)
25. Kabat, P., Ludwig, F., van der Valk, M., & van Schaik, H. (Eds.). (2012). Climate change adaptation in the water sector. Routledge.
26. Kahare, P. (2014). Climate Change and Africa: new report outlines continent's hotspots. African Arguments. Available from: <http://africanarguments.org/2014/06/03/climate-change-and-africa-new-report-outlines-continents-hotspots-by-peter-kahare/>
27. Kibwika, P., Nassuna-Musoke, M., Birungi-Kyazze, F., SSeguya, H., & Akishule, D. (2013). Status of Human Resource Capacity for Agricultural Innovation in ASARECA National Agricultural Research Systems. ASARECA, Entebbe, Uganda. Available from: <http://asareca.org/~asareca/publication/status-human-resource-capacity-agricultural-innovation-asareca-national-agricultural>
28. Masinde, M., & Bagula, A. (2011). ITIKI: bridge between African indigenous knowledge and modern science of drought prediction. *Knowledge Management for Development Journal*, 7(3), 274-290.
29. Masters, L., & Duff, L. (2011). Overcoming barriers to climate change adaptation implementation in Southern Africa. African Books Collective.
30. Mignouna, H. D., Abang, M. M., Omany, G., Nang'Ayo, F., Bokanga, M., Boadi, R., Muchiri, N & Terry, E. (2008). Delivery of Agricultural Technology to Resource-poor Farmers in Africa. *Annals of the New York Academy of Sciences*, 1136(1), 369-376.
31. Molua, E. L., Benhin, J., Kabubo-Mariara, J., Ouedraogo, M., & El-Marsafawy, S. (2010). Global climate change and vulnerability of African agriculture: implications for resilience and sustained productive capacity. *Quarterly Journal of International Agriculture*, 49(3), 185-214.
32. Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the national academy of sciences*, 104(50), 19680-19685.

33. Munang, R., & Andrews, J. (2014). Despite climate change, Africa can feed Africa. *Africa Renewal*, Special Edition on Agriculture 2014, 6. Available from: <http://www.un.org/africarenewal/magazine/special-edition-agriculture-2014/despite-climate-change-africa-can-feed-africa>
34. Mutegei, J., & Zingore, S. (2014). Integrated Soil Fertility Management Strategies for Climate Change Adaptation in Africa. In 20th World Congress of Soil Science pp. 635-635.
35. Nandozi, C.S., Majaliwa, J.G.M., Omondi, P., Komutunga, E., Aribi, L., Isubikalu, P., Tenywa, M.M., Massa-Makuma, H. (2012). Regional climate model performance and prediction of seasonal rainfall and surface temperature of Uganda. *African Crop Science Journal*, Issue Supplement s2 20(2):213 - 225.
36. Niang I, Ruppel OC, Abdrabo MA, Essel A, Lennard C, Padgham J, Urquhart P (2014) Africa. In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, EbiKL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) *Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, pp 1199–1265
37. O'Loughlin, J., Linke, A. M., & Witmer, F. D. (2014). Effects of temperature and precipitation variability on the risk of violence in sub-Saharan Africa, 1980–2012. *Proceedings of the National Academy of Sciences*, 111(47), 16712-16717.
38. Ondiege, P., Moyo, J. M., & Verdier-Chouchane, A. U. D. R. E. Y. (2013). Developing Africa's Infrastructure for Enhanced Competitiveness. In *World Economic Forum (eds), The Africa Competitiveness Report*.
39. Quiroz, R., Harahagazwe, D., Condori, B., Barreda, C., de Mendiburu, F., Amele, A., Anthony, D., Atieno, E., Bararyenya, A., Byarugaba, A.A., Demo, P., Guerrero, J., Kowalski, B., Anthony Kude, D., Lung'aho, C., Mares, V., Mbiri, D., Mulugeta, G., Nasona, B., Ngugi, A., Njeru, J., Ochieng, B., Onditi, J., Parker, M., Randrianaivoarivony, J.M., Schulte-Geldermann, E., Tankou, C.M., Woldegiorgis, G., & Worku, A. (2014). Potato yield gap analysis in SSA through participatory modeling: Optimizing the value of historical breeding trial data. CIP Working Paper. Available from: <http://humidtropics.cgiar.org/wp-content/uploads/downloads/2014/04/Potato-Yield-Gap-Analysis.pdf>
40. Rajaonarison, H. M. (2014). Food and human security in Sub-Saharan Africa. *Procedia Environmental Sciences*, 20, 377-385.
41. Reich, P.F., Numben, S.T., Almaraz, R., & Eswaran, H. (2001) Land resources stresses and desertification in Africa. *Agro-Science* 2(2):1–10. doi:10.4314/as.v2i2.1484
42. Ringler, C., Zhu, T., Cai, X., Koo, J., & Wang, D. (2010). Climate change impacts on food security in sub-Saharan Africa. *International Food Policy Research Institute (IFPRI) Discussion Paper*, 1042. Available from: <http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/6983>
43. Sanchez, P.A., Palm, C.A., Buol, S.W. (2003). Fertility capability soil classification: A tool to help assess soil quality in the tropics. *Geoderma*, 114, 157–185.
44. Schaffnit-Chatterjee, C. (2014). Agricultural value chains in Sub-Saharan Africa: From a development challenge to a business opportunity. Deutsche Bank AG. Available from: [https://www.dbresearch.com/PROD/DBR\\_INTERNET\\_EN-PROD/PROD0000000000033152/Agricultural+value+chains+in+Sub-Saharan+Africa%3A+F.PDF](https://www.dbresearch.com/PROD/DBR_INTERNET_EN-PROD/PROD0000000000033152/Agricultural+value+chains+in+Sub-Saharan+Africa%3A+F.PDF)
45. Schlenker, W., & Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. *Environmental Research Letters*, 5(1), 014010.
46. Schmidhuber, J., & Tubiello, F. N. (2007). Global food security under climate change. *Proceedings of the National Academy of Sciences*, 104(50), 19703-19708.
47. Shiferaw, B., Tesfaye, K., Kassie, M., Abate, T., Prasanna, B. M., & Menkir, A. (2014). Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. *Weather and Climate Extremes*, 3, 67-79.
48. Songok CK, Kipkorir EC, Mugalavai EM (2011) Integration of indigenous knowledge systems into climate change adaptation and enhancing food security in Nandi and Keiyo districts, Kenya. In: Filho WL (ed) *Experiences of climate change adaptation in Africa*. Springer, Hamburg, pp 69–95.
49. Steenwerth, K. L., Hodson, A. K., Bloom, A. J., Carter, M. R., Cattaneo, A., Chartres, C. J., ... & Jackson, L. E. (2014). Climate-smart agriculture global research agenda: scientific basis for action. *Agriculture & Food Security*, 3(1), 11.
50. Thomas, T., & Rosegrant, M. (2015). Climate change impact on key crops in Africa: Using crop models and general equilibrium models to bound the prediction, In: *Climate change and food systems: global assessments and implications for food security and trade*, Aziz Elbehri (editor). Food Agriculture Organization of the United Nations (FAO), Rome, 2015.
51. Tully, K., Sullivan, C., Weil, R., & Sanchez, P. (2015). The State of Soil Segregation in Sub-Saharan Africa: Baselines, Trajectories, and Solutions. *Sustainability*, 7(6), 6523-6552.
52. Vanlauwe, B., Descheemaeker, K., Giller, K. E., Huising, J., Merckx, R., Nziguheba, G., wEND... & Zingore, S. (2014). Integrated soil fertility management in sub-Saharan Africa: unraveling local adaptation. *Soil Discuss*, 1, 1239-1286.
53. Villanueva, P. S., & Hiraldo, R. (2011). Climate Change and Agriculture in Sub-Saharan Africa: New Concerns, Old Arguments?. Occasional Paper 003. *Future Agricultures*. Available from: <http://www.future-agricultures.org/publications/research-and-analysis/occasional-papers/1463-climate-change-and-agriculture-in-sub-saharan-africa-new-concerns-old-arguments/file>
54. Ward, P. S., Florax, R. J., & Flores-Lagunes, A. (2014). Climate change and agricultural productivity in Sub-Saharan Africa: a spatial sample selection model. *European Review of Agricultural Economics*, 41(2), 199-226.
55. Williams, A. P., & Funk, C. (2011). A westward extension of the warm pool leads to a westward extension of the Walker circulation, drying eastern Africa. *Climate Dynamics*, 37(11-12), 2417-2435.
56. Ziervogel, G., Bharwani, S., & Downing, T. E. (2006). Adapting to climate variability: pumpkins, people and policy. *Natural Resources Forum* 30 (2006) 294–305.